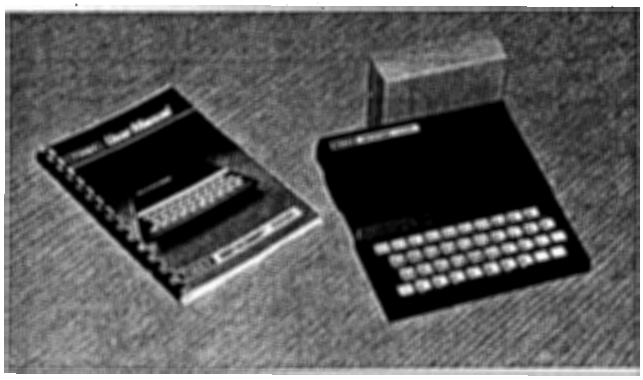


the ZX-81/TS-1000 controller:
new use for old computers

Four ICs in interface circuit link computer to outside world

If you've been to a hamfest lately, or read the back pages of any ham magazine, you've probably seen used Sinclair ZX-81 or Timex/Sinclair 1000 computers selling for less than $20*. During their heyday several years ago, these computers — which originally sold for $150 — led the way for the personal computer revolution. Although the Sinclair was somewhat of a marvel at the time, many users soon became disenchanted with it, either because of the small membrane keyboard or the difficulty of interfacing it with peripherals.

Perhaps you've stashed a Sinclair away in your junkbox in hope of someday finding something to do with it. Or perhaps you've toyed with the idea of picking one up at a hamfest but decided otherwise. Never mind. *Get one.*

This small, cheap-looking computer has computing power comparable to much more expensive computer systems. The key to harnessing this power is simply finding an application that takes advantage of its strengths. For while it's admittedly disappointing for some applications — such as word processing — it's ideally suited for control functions and can be easily programmed for a host of controller applications.

In this article, a simple circuit using only four ICs will be presented, along with a detailed example of how to program your ZX-81 or TS-1000 computer for I/O applications.

With this simple interface circuit attached to the memory port of either the ZX-81 or TS-1000, you instantly gain the ability to communicate with the outside world. All sorts of applications — including satellite rotor controls, digital voltmeters, morse code sending and receiving, educational demonstrations, and many others — easily follow once you have an I/O interface. I developed this circuit as part of a school project a few years ago when I used the TS-1000 computer to send and receive RTTY. Since then, I've been selling the information contained herein at cost to Sinclair computer enthusiasts at local hamfests and by mail. If you've been wondering how to make your ZX-81 or TS-1000 perform some useful tasks and are interested in a neat one-evening construction project, then read on.

what is a controller?

While many computers are used for computation, word processing, or data management, many "small" computers, composed of just a microprocessor and a handful of special-purpose chips are built strictly for *controller* applications. For example, microprocessor circuitry is now being installed in automobiles. A microprocessor is programmed with a simple looping program which does nothing more than continuously monitor various data lines and then branch to a par-

By Ted S. Rappaport, N9NB, Box 283, Electrical Engineering, Purdue University, West Lafayette, Indiana 47907

*TS-1000 computers ($19.95), manuals ($2.95), and accessories are available from Hal-Tronix, Inc., Dep't HR, P.O. Box 1101, Southgate, Michigan 48195 (313-285-1782).

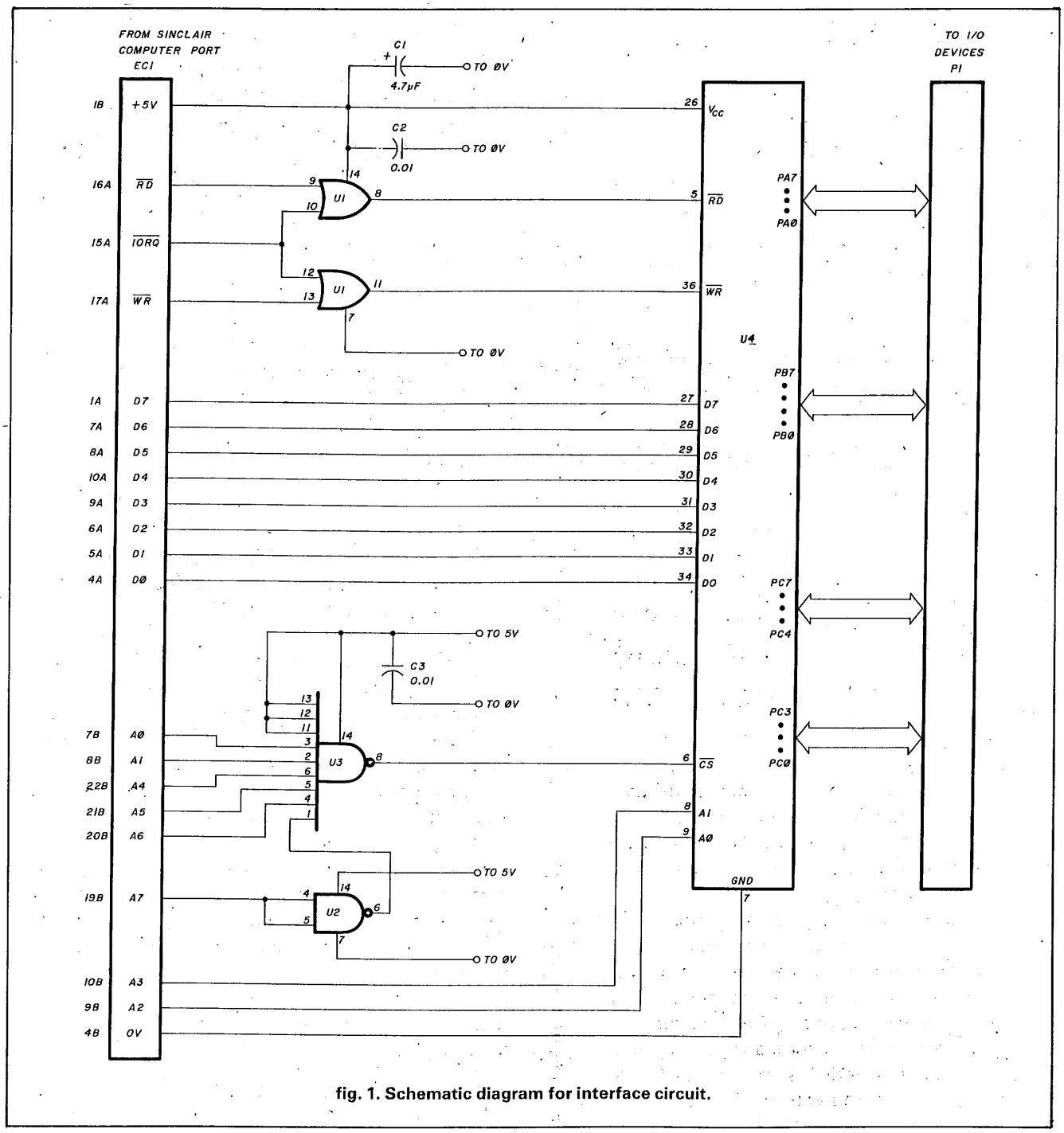


fig. 1. Schematic diagram for interface circuit.

ticular part of the program when specific lines change state. These input/output (I/O) lines are connected to hardware such as the fuel level sensor, the climate control console, and thermal sensors under the hood and inside the passenger compartment. When the driver wants to raise the car's interior temperature to 75 degrees, he or she simply presses a button, entering the desired temperature. The program in the microprocessor is continuously looping, searching for any changes on the input data lines. Finding that the driver has activated the climate control console line, the program then branches to the subroutine designed to effect the desired climate change. In this case, the information (75 degrees) is read into the microprocessor as digital data and a control signal is then sent out to the appropriate hardware (in this case, the heater on/off switch). While this is an overly simplified version of what is actually done in today's automobiles, it illustrates one typical application of a controller.

Of key importance is the fact that in such applications, the computer is programmed to handle a variety of input signals from external hardware and issue

Table 1. Parts list for Interface Circuit (fig. 1).

Schematic Designator	Description
C1	4.7 μF electrolytic capacitor
C2	0.01 μF capacitor
C3	0.01 μF capacitor
EC1	2 row x 23-pin edge connector; 0.1-inch spacing, pin length at least 0.75-inch.
P1	DB-25 D-connector
U1	74LS32 Quad two-input OR chip
U2	74LS00 Quad two-input NAND chip
U3	74LS30 Eight-input NAND chip
U4	8255 Programmable Interface Chip

Miscellaneous:
Single-sided circuit board
Jumper wires (at least 10)
Project box (UNIBOX UB270-130)

control signals to external hardware. Because the controller's program is simple and repetitive, it doesn't require much memory. The 2K of memory in the ZX-81 and TS-1000 is more than enough to program even a very complex controller. We can also take advantage of the computer's high-level (BASIC) capability to simplify programming the computer for controller applications. An understanding of machine language is important, though, since the I/O interface must allow exchange of data on a level lower than BASIC; this is done through the *PEEK* and *POKE* commands.

description of interface circuit

With the interface circuit connected to the port of the ZX-81 or TS-1000, very fast data signals which appear on the data bus of the computer can be latched by the interface circuit and sent as control signals to external hardware (I/O devices). Similarly, in conjunction with the interface circuit, the computer can read in very fast asynchronous signals from external hardware and use the received signals to make decisions in software.

Figure 1 is the schematic diagram of the I/O interface. A complete parts list appears in **table 1**. Note that no power supply is needed for the interface; all four ICs are conveniently powered by the computer's internal 5-volt supply (the voltage is made available at the computer port).

The heart of the interface circuit is U4, the 8255 programmable peripheral interface (PPI) chip. U1, U2, and U3 serve to decode the address signals generated by the computer. After much trial and error, I found that it's possible to access four I/O address locations not used by any of the internal computer circuitry. These address locations — 115, 119, 123, and 127 (decimal) — may be used to activate any external device connected to the computer port. For my interface circuit, these four address locations are used to access U4, which in turn directs the flow of data between any external I/O device and the computer. In **table 2**, I've shown the addresses used to control the various registers of U4. While some of the basics on how to use U4 will be spelled out later, more details can be found in any Intel databook or in Goldsbrough's *Microcomputer Interfacing with the 8255 PPI Chip*.[2]

Table 2. Operation of 8255 PPI chip (U4).

I/O Instruction	I/O Address	Operation
IN	115	Read from Port A
IN	119	Read from Port B
IN	123	Read from Port C
OUT	115	Write to Port A
OUT	119	Write to Port B
OUT	123	Write to Port C
OUT	127	Write to Control Register

When laying out a circuit board, I decided that it would be nice to have the ability to add components or connectors in the future. (I call the upper portion of the board, where there are several inches of 0.1-inch spaced holes, the "playground" area.) By adding components and appropriate jumper wires, it's possible to expand the interface circuit. The single-sided board negative I used, shown in **fig. 2**, requires ten insulated jumper wires, which should be installed on the foil (non-component) side of the circuit board after all of the components are mounted (see **table 3**). Pads are available on the circuit board to permit easy soldering of each jumper. I used 16 additional jumpers to route all eight of the port A pins, four of the port B pins, and four of the port C pins from U4 to molex pins attached on the top of the "playground" area. These molex pins mate with headers that allow for easy detachment of the data lines from I/O hardware or from a case-mounted connector. You may wish to use just one pin or all 24 pins available on U4 for I/O data exchange. Use as many data lines as you need.

The component layout for the circuit board (**fig. 2**) is shown in **fig. 3**. When mounting the ICs, be sure to use a low-wattage soldering iron since the pads are delicate. I strongly recommend the use of sockets for each of the four ICs.

All of the components are easy to acquire at hamfests or electronic shops, except, perhaps, for the 46-pin connector used to attach the interface board to the computer memory port. The connector type is the same as that used on ZX-81 and TS-1000 peripherals such as the 16K RAM-pack, and is a 46-pin, double-sided edge connector with 0.1-inch spacing between contacts. I found that you have to buy a sturdy con-

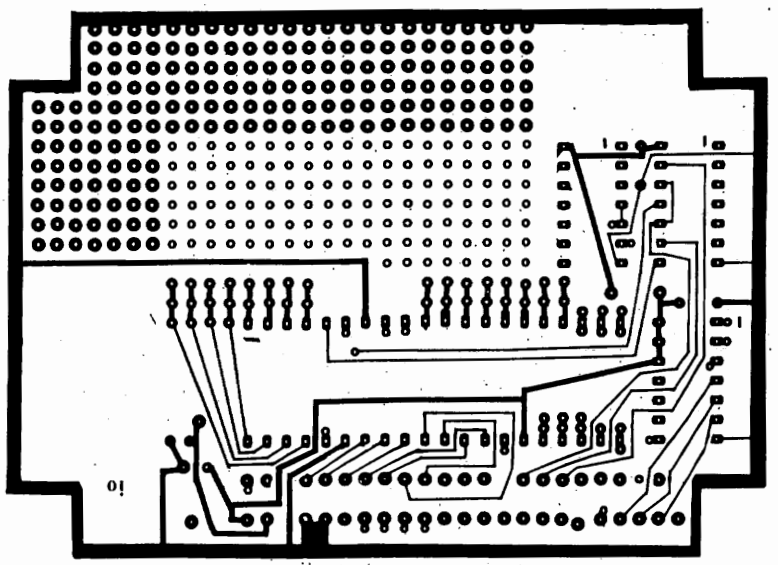


fig. 2. Single-sided circuit board artwork for I/O interface circuit.

Table 3. Jumper wires needed for single-sided circuit board. These connections should be made after all other components are soldered in place.

Jumper between: U1, pin 11 and U4, pin 36
Jumper between: U2, pin 5 and EC1, pin 19B
Jumper between: U2, pin 6 and U3, pin 1
Jumper between: U3, pin 2 and EC1, pin 7B
Jumper between: U3, pin 3 and EC1, pin 8B
Jumper between: U3, pin 8 and U4, pin 6
Jumper between: U3, pin 16 and U1, pin 16
Jumper between: U4, pin 8 and EC1, pin 10B
Jumper between: U4, pin 9 and EC1, pin 9B
Jumper between: U4, pin 27 and EC1, pin 1A

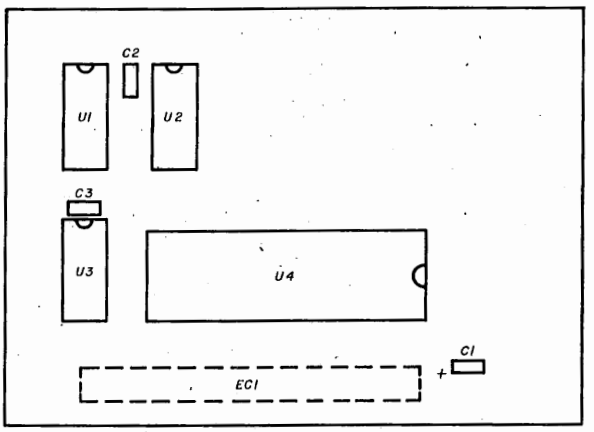


fig. 3. Component layout for interface circuit — view from component side (EC1 mounted on FOIL SIDE).

nector and be prepared to use a Dremel tool or a small saw to cut a larger connector down to correct size. But be careful: I bought a 60-pin, double-sided connector for less than $1.00 from a military surplus dealer at a hamfest. Eagerly, I took the new connector home, cut it to length, and soldered it onto the board. After a couple of trial fits on the memory port of the computer, the connector crumbled into tiny bits! It was a real pain to have to chop off the faulty connector and resolder a new one onto the board! You may notice from the accompanying photographs that the connector must be soldered on the foil side of the board, and protrudes from that side of the board as well.

The entire cost of components is well under $20. The construction time is fast — one evening should be sufficient.

I was able to find attractive plastic boxes made by UNIBOX[3] at a local Radio Shack for less than $4.00 each. The circuit board fits neatly inside, and only two rectangular holes have to be cut into the box: a 0.5 x 2.5-inch hole to allow the 46-pin edge connector to protrude from the circuit board, and a 0.5 x 1.0-inch hole on the other side of the box to allow I/O wires to be fed to a D-connector mounted on the exterior (see **fig. 4**).

interface software

You can add all the hardware in the world to a computer, but it won't serve any useful purpose unless you know how to program the computer effectively. In this section a programming example for an application of the interface circuit is given, and a review of how to

use the ZX-81 and TS-1000 *PEEK* and *POKE* commands is presented.

In order to perform data exchanges between I/O devices and the computer, it's first necessary to set up the I/O format on U4. U4 has 24 pins which are usable for data exchange. These pins are partitioned into three groups of eight pins. Each group of eight pins is called a *port.*

Any program written for I/O control should begin with an initialization stage. This initialization sets the data flow of the ports on U4. For example, you may want to program the eight data lines of port A for output (data sent to the I/O device from the computer) and have the eight data lines of port B programmed for input (data sent from the I/O device to the computer). While ports A and B require that all eight pins be either input or output, Port C allows for four pins to be input and four to be output. Of course, Port C may also be programmed for all eight pins to be either input or output.

While it's beyond the scope of this article to teach assembly language and machine code programming, let me assure you that mastering them is not difficult. If you find the example in this article insufficient, you may wish to read Chapters 1, 2, and 5 in Hordeski's easy-to-read *Microprocessor Cookbook.*[5]

The following example details the simplicity of controller software. Consider an alarm system that monitors the status of eight windows around the house. Three wires (ground, +5 volts, and data status line) could be routed to each of eight windows. A small switch could be mounted by each window so that if the window is shut, a low-logic level (0 volts) exists on the status line. If any of the windows are open, we want the computer to recognize this and sound a bell. For this case, we may use all eight pins of Port A for input (to read the status of each of the eight windows), and may use Port B for output (although we need to use only one of the eight pins to output a control signal for the alarm). Since we're not using Port C, we don't care what it's programmed for! By connecting the status line of each window to individual pins of Port A, we can read the status of each window into the computer. If we use a simple transistor switch to activate the bell, one of the pins from Port B can be connected to the gate of the transistor switch. When a window is discovered to be open, the computer then sends out a high-logic level (5 volts) to the alarm pin (as well as the unused pins) on Port B, thus sounding the bell.

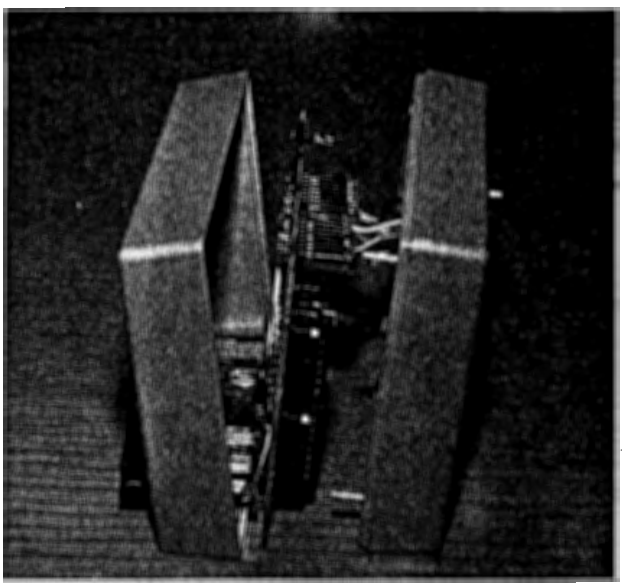


fig. 4. The circuit board fits into the project box. Be sure to use an edge connector with at least ¾" of pin length to allow clearance when the circuit is plugged into the computer port. It is convenient to have a connector on the back of the box for easy access to the I/O lines.

The programming steps for the window alarm example would be as follows:

1. Initialize data flow on Ports A, B, and C.
2. Look at input data from windows.
3. If any of the input data bits is "1," sound alarm.
4. If the input data is all "0," then go to step 2.

Notice that once the data flow is initialized on U4, no further action is required unless the power is unplugged or U4 is reprogrammed. The assembly language program for this example follows (comments are included in parenthesis):

```
(Initialization):
LD A, 144 (144 = 10010000. This programs Port A for
input, Ports B, C for output. We load 144 into ac-
cumulator.)
OUT 127,A (Send contents of accumulator 144 to the
U4 control register, which is located at ADDR 127.)

(Monitor window data):
loop  IN A, 115. (Read in the eight-bit data at ADDR
      115 — Port A — and place data in the ac-
      cumulator.)

JRZ, loop  (Compare the eight bits of data in accumu-
           lator to the all-zeros data word 00000000;
           if all eight bits of data are zeros, then jump
           back to loop and continue to monitor.)

(If program gets to this point, then sound the alarm!):

LD A, 255 (Load accumulator with all-ones word,
          11111111)

OUT 119, A (Send the accumulator contents out to
           Port B; this sounds the alarm).
```

The preceding assembly language program, when written in machine code, requires only 13 bytes of memory! It's entered into the computer via the *POKE* command. The conversion from assembly language mnemonics to machine opcodes is given in the ZX-81 and TS-1000 user's manual appendix. For the previous program, the machine code that would be POKEd is given in **table 4.**

Although not illustrated in this example, it's simple to monitor your I/O activity by going back and forth between BASIC and machine code. In this case, it would have been easy to see on the computer monitor which particular window (or windows) were opened by simply passing the Port A data to the b-c register pair in the machine code program, and then by returning to BASIC by way of the USR command and printing the value of the USR function on the screen.

machine code within BASIC programs

To store a machine code program in the computer, you must first set aside some memory by using a REM statement (usually the first line in your BASIC program). The REM statement sets aside successive memory locations which are never written over, thereby allowing you to store machine code programs safely. Machine code programming may be saved on tape by using the *SAVE* command.

A machine code program is run in sequence by using the USR command, where the argument of the USR command is the address location of the first machine language opcode. The computer returns to the BASIC program once the return opcode (201) is encountered, and assigns the decimal value of the b-c register contents to the variable name to which the USR function is equated. In this manner, it's possible to pass data from machine code programs (and consequently data from external I/O devices) to BASIC. Or you may use the *PEEK* command in a BASIC program to retrieve data from dedicated memory locations in your machine code storage area (REM statement). Either way, it's a simple chore to transfer data from "real world" devices to your computer. By using the *POKE* command in a BASIC program, you may place data from BASIC into data locations of machine code programs. Note that this allows you to make keyboard entries and have these entries correspond to control signals for I/O devices.

When you're ready to enter a machine code program into the computer, clear the computer's memory and begin as if you were writing a new BASIC program. Enter **line 1** as a REM statement, filling in as many letters in the REM statement as the number of bytes required in your machine program. It doesn't matter what you put in your REM statement, because after you *POKE* in your machine code, the REM statement appears as gibberish on the screen. For the TS-1000 computer, the first usable memory slot once a REM statement is entered is 16514. Use the *POKE* command to place the machine code in sequential memory locations starting with 16514. Upon completing the entry of your machine code, place the opcode 201 in the very next memory location following your last program opcode. At this point it's a good idea to save your program on tape (even though it's only a single REM statement). That way if anything happens — for example, if junior unplugs your computer — you don't have to re-*POKE* your entire program! For the machine code in **table 4**, the following would be entered into the computer:

Table 4. Machine code for programming example.

Assembly language instruction	Machine code
LD A, 144	62
	144
OUT 127, A	211
	127
IN A, 115	219
	115
JRZ, -4	40
	252
LD A, 255	62
	255
OUT 119, A	211
	119
RETURN TO BASIC	201

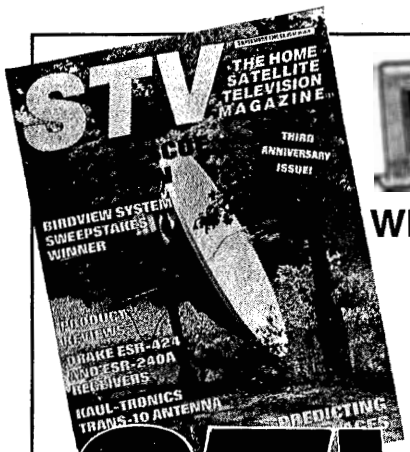
```
POKE 16514,62 (press enter)
POKE 16515,144 (press enter)
POKE 16516,211 (press enter)
. . . .
. . . .
. . . .
POKE 16524,211 (press enter)
POKE 16525,119 (press enter)
POKE 16526,201 (press enter)
```

To verify that the opcodes are in memory, you may use the *PEEK* command to see what the computer has stored.

In order to execute your machine code, you must have a BASIC statement that contains the USR function. For the window alarm program, your next program line (following the REM statement) could be:

2 LET WINDALARM = USR (16514)

By running this simple two-line BASIC program, your Sinclair computer executes the machine code and is able to communicate with external devices through the use of the interface circuit! If the machine code was written so that the Port A data was placed in the b-c register pair, then the value of the variable WINDALARM, which can be viewed on the monitor with a simple print statement such as



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3 PRINT WINDALARM,

could be displayed to indicate (in decimal) the window status.

When using the Sinclair computer as a controller, more than one machine language program can be used. It's often convenient to write several *subroutines* in machine code, and store them all in succession in the first REM statement. (Remember they're separate to the computer when they end in the opcode 201). In this manner, your BASIC program can consist of various calls to the subroutines by using USR functions with the appropriate memory addresses in the REM storage.

conclusion

In this article I've discussed the hardware and software needed to provide a communication path between your Sinclair ZX-81 or Timex/Sinclair 1000 computer and any I/O device you might wish to control or monitor. With the price of these computers so low, even those with the tightest budgets can afford to experiment with computer control! By now, you may already have an idea for a controller application in your shack. If you take an evening out to build this circuit and spend a few hours reviewing machine language programming, you'll be amazed at what your small but mighty computer can do!

references

1. *Intel* is a trademark of Intel Corporation. Information on Intel products may be obtained from Literature Department, Intel Corporation, 3065 Bowers Avenue, Santa Clara, California 95051.
2. P.F. Goldsbrough, *Microcomputer Interfacing with The 8255 PPI Chip*, Howard W. Sams, Publisher, 1979.
3. UNIBOX, Amerex Corporation, Riverside, California 92502.
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